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ILLINOIS FLUID INJECTION RESEARCH REVIEWED

By
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Illinois Fluid Injection Research Reviewed

By Frederick Squires*

The oil pools of Illinois present unique characteristics which for production purposes have called for special study. These investigations have resulted in the inauguration of new techniques such as wide well-spacing, use of old wells for input and output, subsurface flooding with salt water from higher strata, and others of equal specialization. Some of these are already in practical use in oil fields and others are in process of development for field operation. Many of the publications covering these new tecniques are now out of print and it is the purpose of this paper to present them briefly so that they will be again available.

The subjects herein described are: (1) Conjoint injection of gas and liquid; (2) Selective plugging with water; (3) Flooding with old wells; (4) Exploring with injected gas; (5) Water encroachment tests; (6) Equipment to solve new conditions; (7) Non-ferrous casings; and (8) Thermal drive.

1. Conjoint Injection of Gas and Liquid

In most oil-bearing structures, gas, oil, and water are under pressure and, except for dissolved gas and connate water, are arranged in horizontal layers according to their respective specific gravities. When wells are drilled into such oil-bearing reservoirs, oil flows because of the differential pressure between the reservoirs and the earth's surface. The out-flow of oil and gas lowers the pressure in the drilled areas and this sets up an inward motion of the surrounding fluids toward the well bores. Natural reservoir pressures can be maintained only when there is inflow from surrounding water through sufficiently permeable sands equal to the outflow of gas and oil from the wells. Under all other conditions the reservoir pressures constantly decrease. Production rate decreases as pressure declines.

Diminution of the volume of oil produced bears a fairly close relationship to presure decline, but pressure decline is not proportional to the volume of oil remaining in the sand: While the pressures differential is falling from maximum to zero, the volume of oil in the reservoir falls from maximum to half of the original content. It is therefore necessary, for best results, to maintain high reservoir pressures. Conjoint injection accomplishes this.

A reservoir that contains water under pressure around its lower perimeter, contacting a central oil body charged with gas in solution, either with or without a gas cap, is in the ideal condition to give up its oil. When pierced by wells, the oil flows. Since this is the ideal setup, the ideal solution for maintaining similar results is the provision of means to keep the pool in its original condition. The logical procedure then must be to inject gas

Figures 2, 3, 4, and 5 also illustrate conjoint injection of gas and liquid. Figure 2 shows the conditions under which the first experiment was conducted. Figure 3 illustrates single water and gas injections. Figure 4 shows conjoint gas and liquid injection, and Figure 5 shows by plan and section an application to a known oil-bearing structure. Figures 2-4 are from Illinois State Geological Survey Circular 103, 1944.

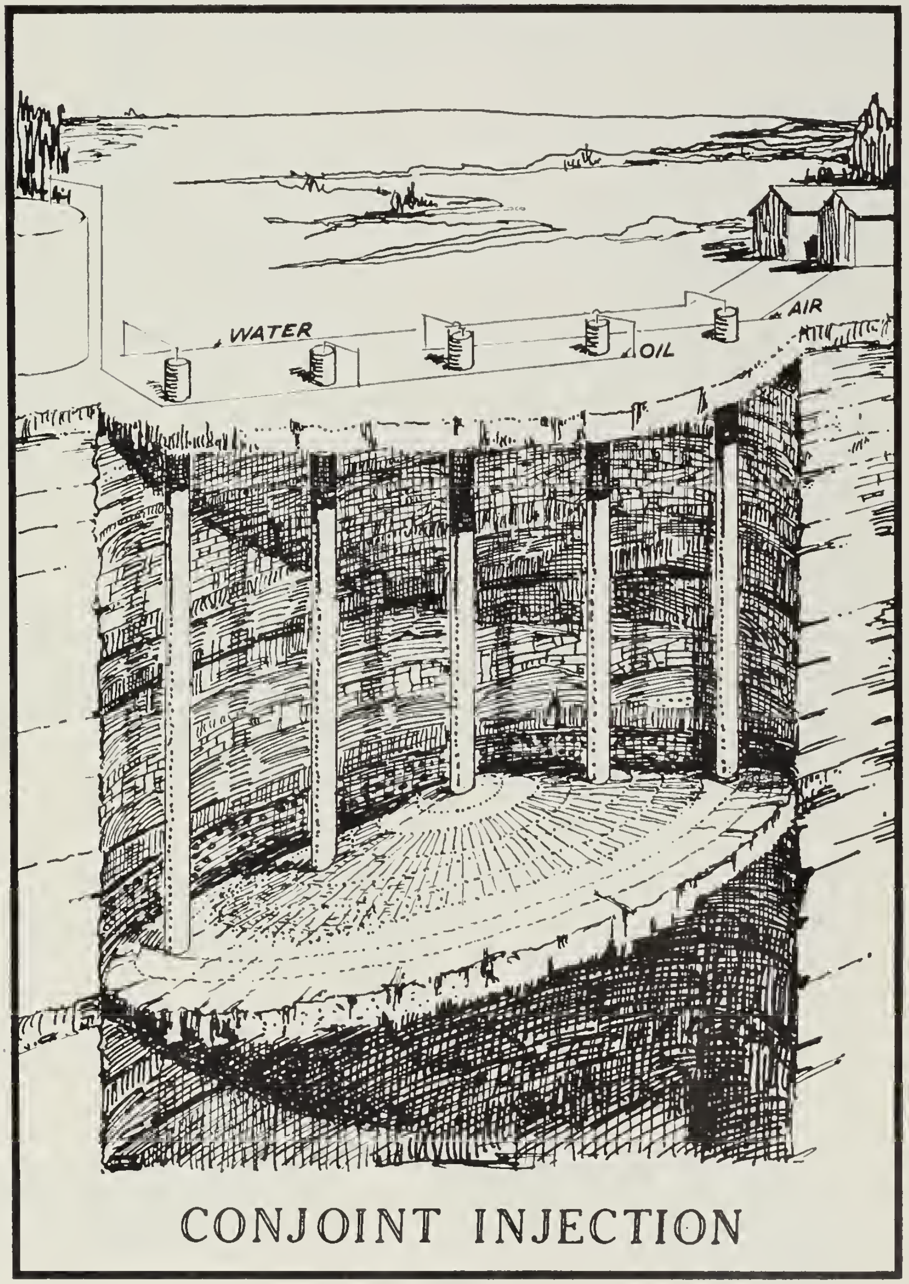

Figure 1

Figure 1 is a cut-away representation of underground conditions in which a domical oil structure is exposed. The center well is the gas injection well, the outermost wells are for water injection, and the wells between air and water are for oil production.

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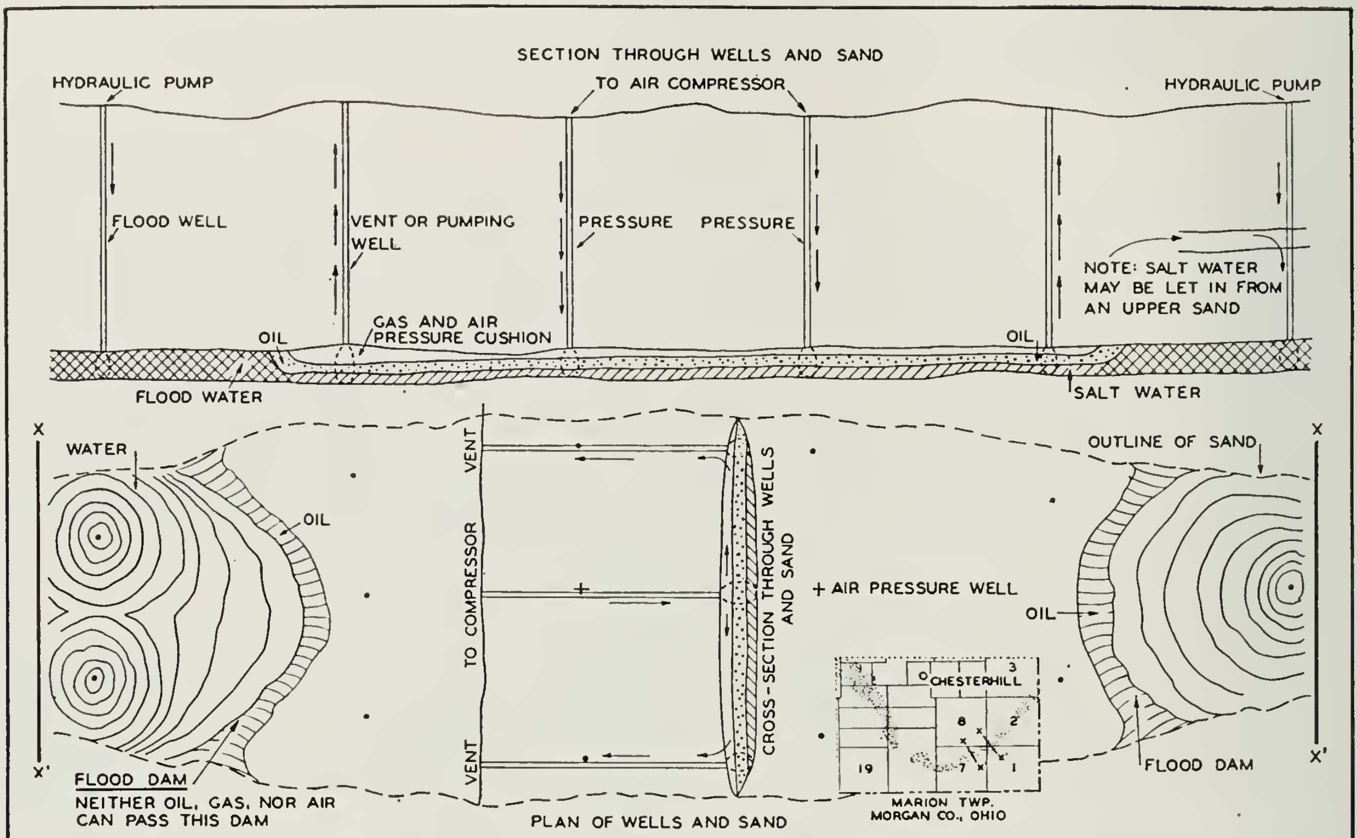

THE STREAK OR BELT CONDITION

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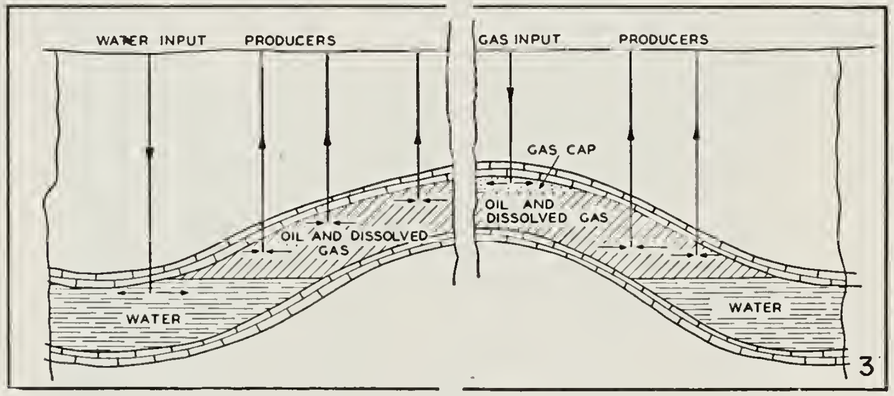

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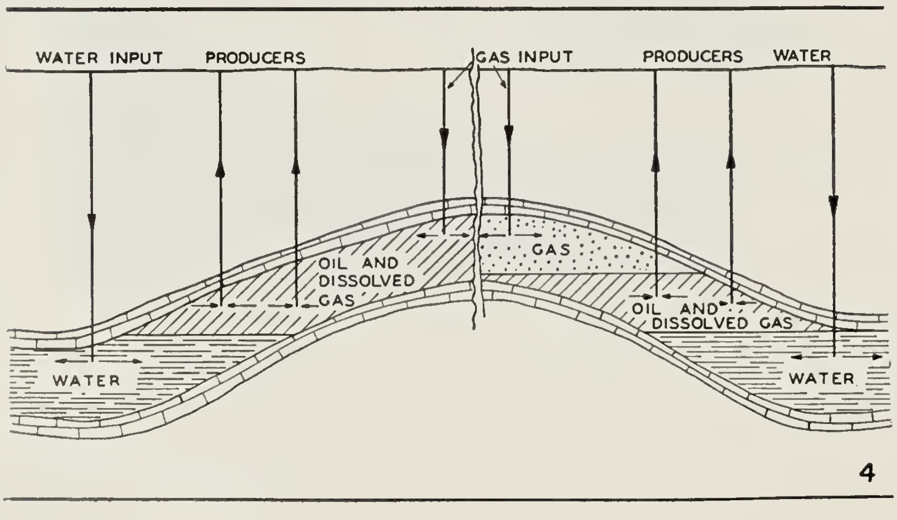

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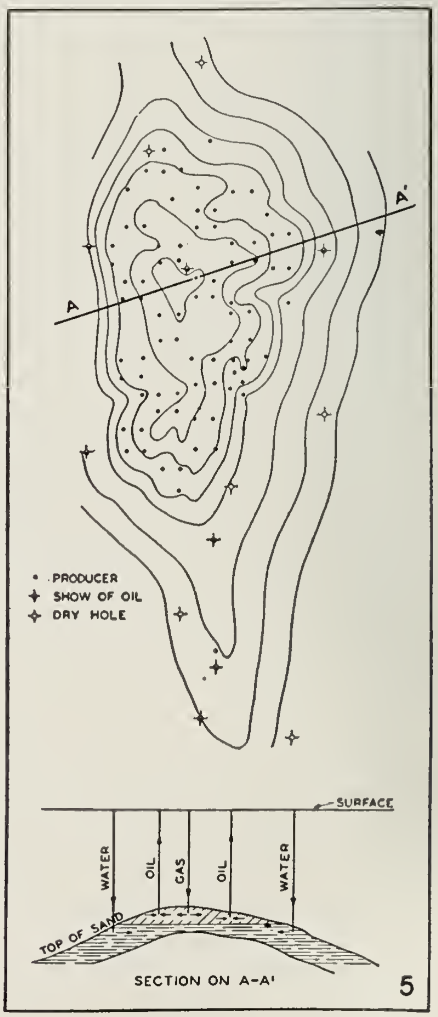

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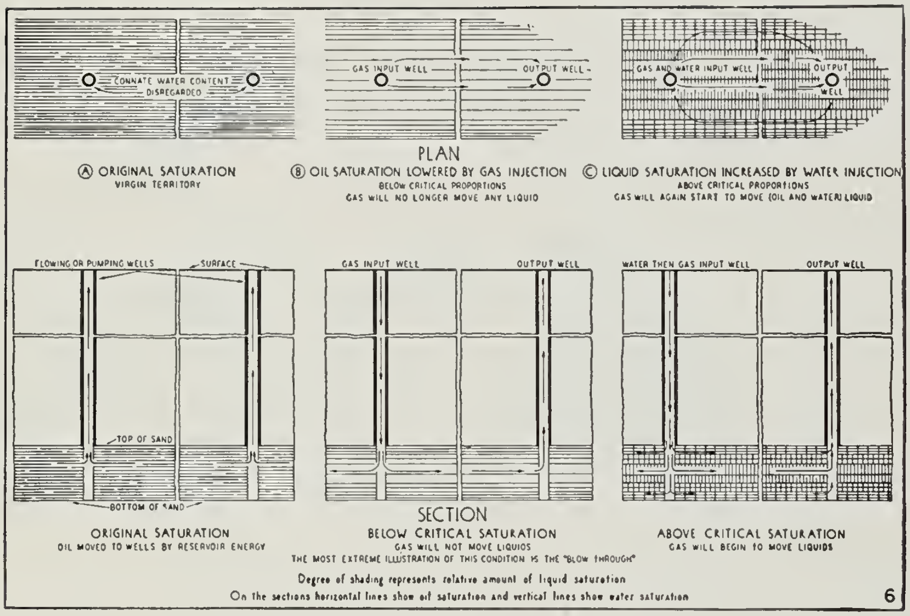


and water conjointly, each in the area where it originally existed. The process is shown in Figures 1 to 5 inclusive.

In field production this method would lend itself best to the production of high-gravity oil from highly permeable sands, on steep structures surrounded by edgewater and topped with gas caps. The Johnsonville pool is well adapted to conjoint injection. This process is now in successful use in the Shuler Jones pool in Arkansas and the West Tepetate field in Louisiana.

Of the available pressure media, the volume of air is limitless and water is abundant. The process conserves the gas (which is wasted in a water-flood) and solves the problem of salt-water disposal. In many states, gas must be returned to the formation as a conservation measure. Conjoint use involves only the addition of water to the already existing gas-injection process.

2. Selective Plugging with Water

The sand between certain input and output wells on gas-repressured properties often provides too easy passage for gas to the detriment of oil production. This is because the liquid content of the sand between such wells has been reduced so far that the sand has become enormously permeable to gas. Since no more oil can be moved by injected gas at the existing liquid saturation of the depleted areas, it is logical to introduce liquid in order to make the sand less permeable to gas. This is illustrated in the drawings, figures 6 and 7.

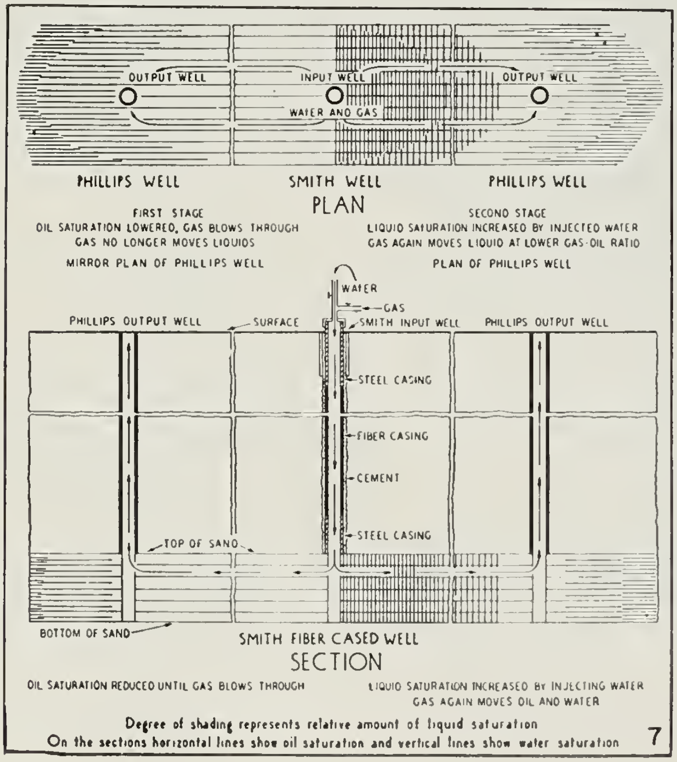
3. Flooding with Old Wells

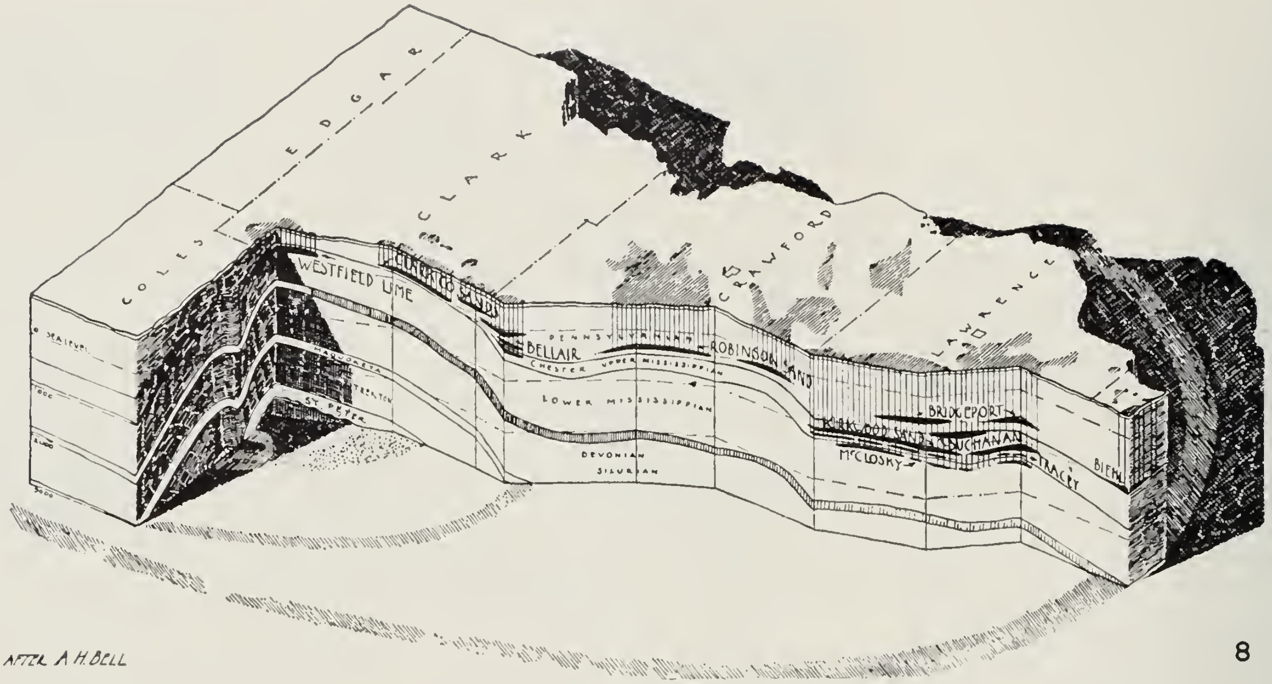
Except for the cost of drilling, permeability and not depth would always determine well spacing for water flooding. The unusually high permeability of many Illinois oil sands suggests that the present well spacing will permit flooding of many areas without new drilling, using old wells only. It would require staggering water-input and oil-producing wells in the old pattern.

Old wells seldom provide reliable subsurface information because cores and good well records are usually lacking. In order to obtain the most important part of the information which would normally be given by the core from a new well, the following three methods are suggested: (1) Caliper and take side-wall cores, determine relative permeability in the well itself by subjecting each vertical foot of the sand to air or water under pressure, as the hole is filled up from the bottom in equal increments, with a self-removable seal. (2) Make a careful study of initial, yearly, and total oil production. Other conditions being the same, a lease which has produced a great deal of oil will still contain more recoverable oil than one of the same area and sand thickness which has produced little. (3) Study present water-oil ratios. A lease with high present and past water-oil ratios will contain less recoverable oil than one which has produced and is producing little water with a comparable amount of oil. The sand is also apt to be too permeable to water.

In a large part of Illinois' producing territory, at least one sand above the oil stratum is charged with salt water under pressure. The oil sands under such water-bearing strata are often highly permeable, and where this is so, it is a practice to gun-perforate the casing opposite the water sand in wells chosen for water inputs and to measure and control the rate of water inflow into the oil sands by means of regulating meters. This is

Figures 6 and 7 show the method by which a selective water plug is applied. The illustrative drawings appeared in the Illinois State Geological Survey's Circular 118, 1945.





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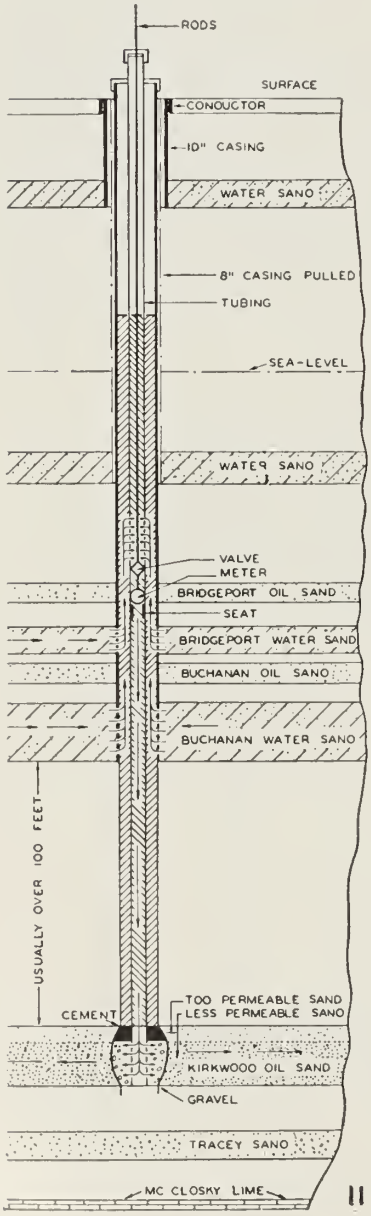

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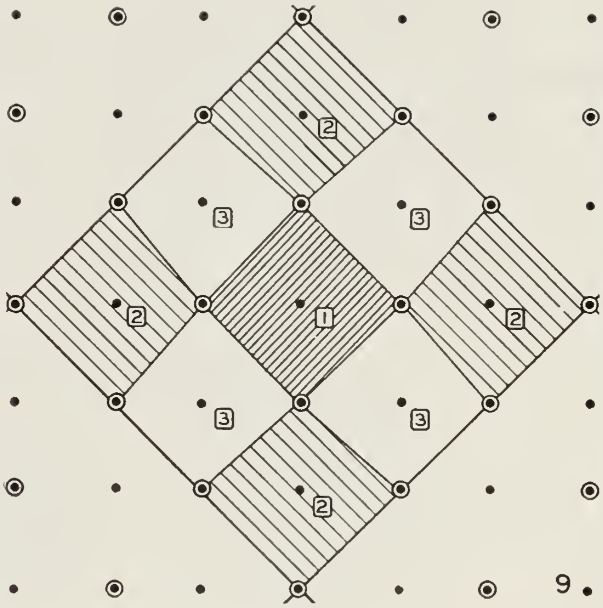

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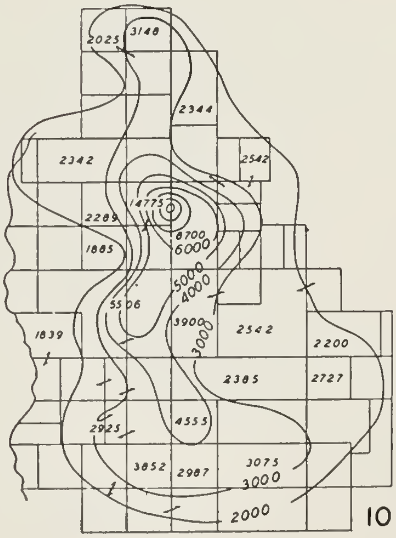

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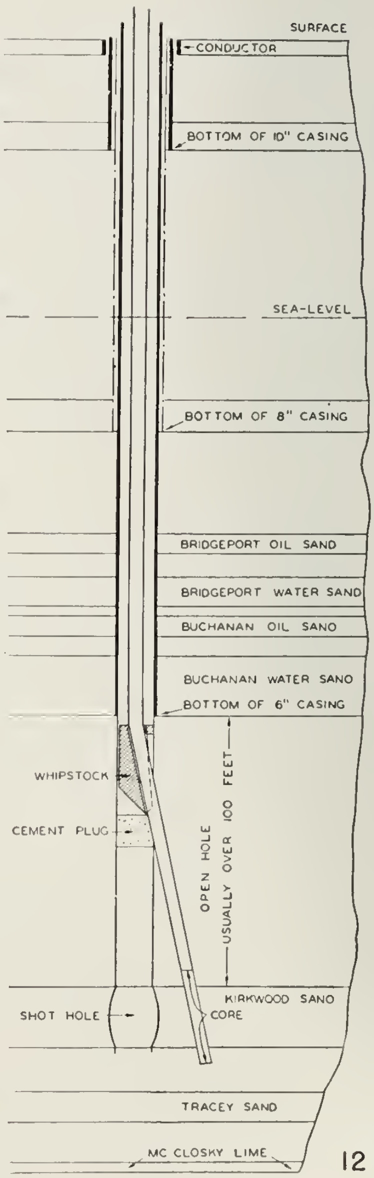

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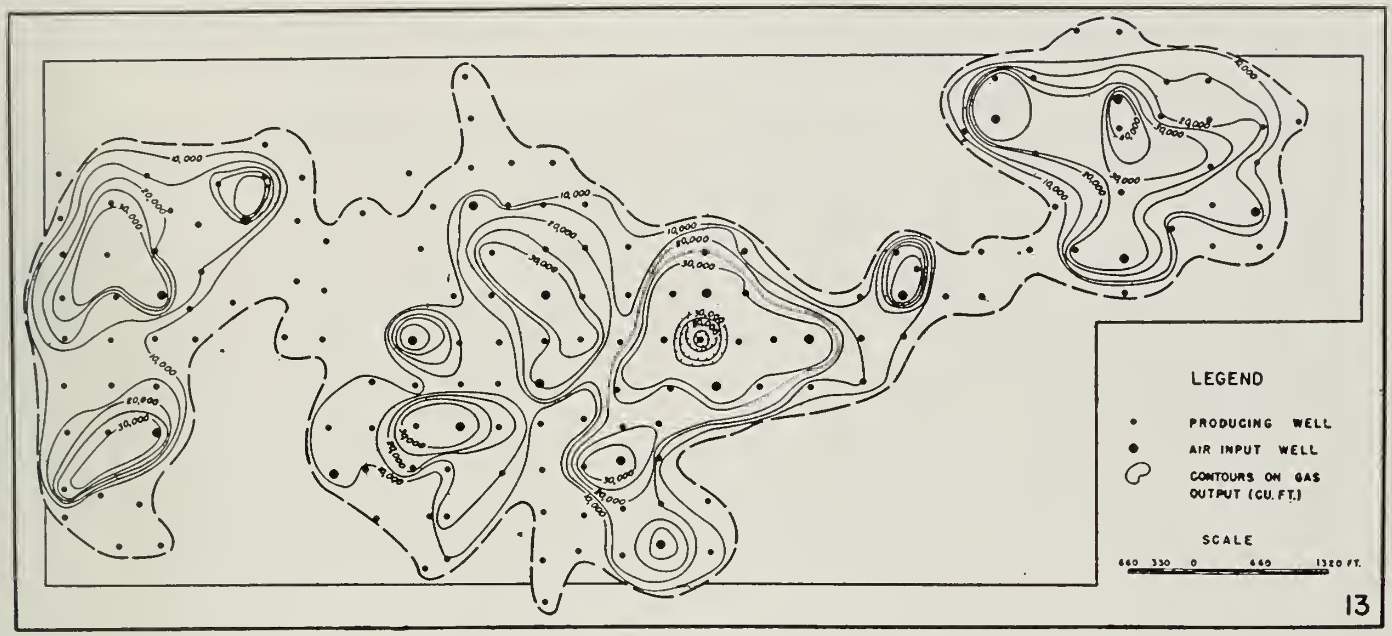


being used successfully on basin McClosky pools. If permeabilities are too low and it is necessary in order to drive enough water into the sand to increase the input pressure by means of pumps, the brine may be raised to the surface, chemically treated, filtered, and pumped back through tubing in the ordinary way. The descriptive drawings are figures 8 to 12 inclusive.

Figures 8, 9, 10, 11, and 12 illustrate the use of old wells for water flooding in the old Southeastern field. Figure 8 shows that wells become progressively deeper from north to south, so that if new wells had to be drilled the expense of flooding would increase in the same direction. Without new drilling the expense would be the same. Figure 9 shows the flooding pattern, using old wells; there are three differently shaped areas. Figure 10, which gives cumulative production per acre, shows that richness of territory varies widely. Figure 11 demonstrates a method of flooding with water from higher sands, and Figure 12 illustrates coring by deflected drilling. From Illinois State Geological Survey's Circular 101, 1943.

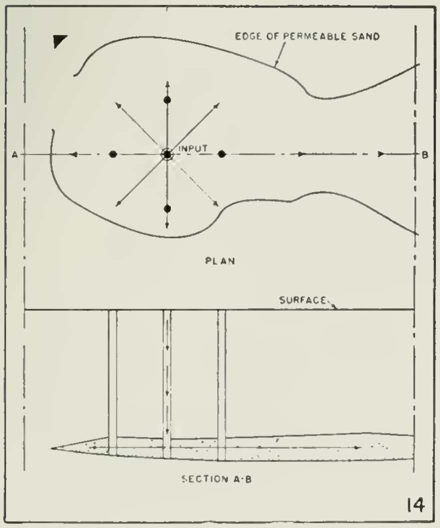
4. Exploring with Gas

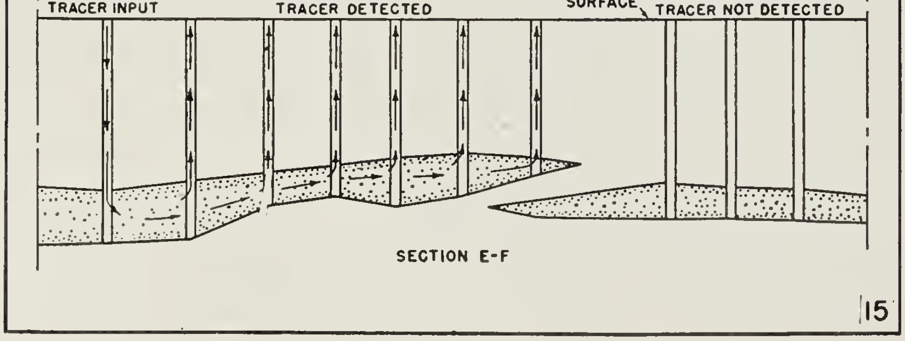
Test by output volume. Contours may be drawn on a map which show the volumes of injected gas produced simultaneously from output wells (Fig. 13). As between wells equidistant from an input well, the permeability of the intervening sand varies directly as the volume of gas traveling from the input well to each surrounding output well.

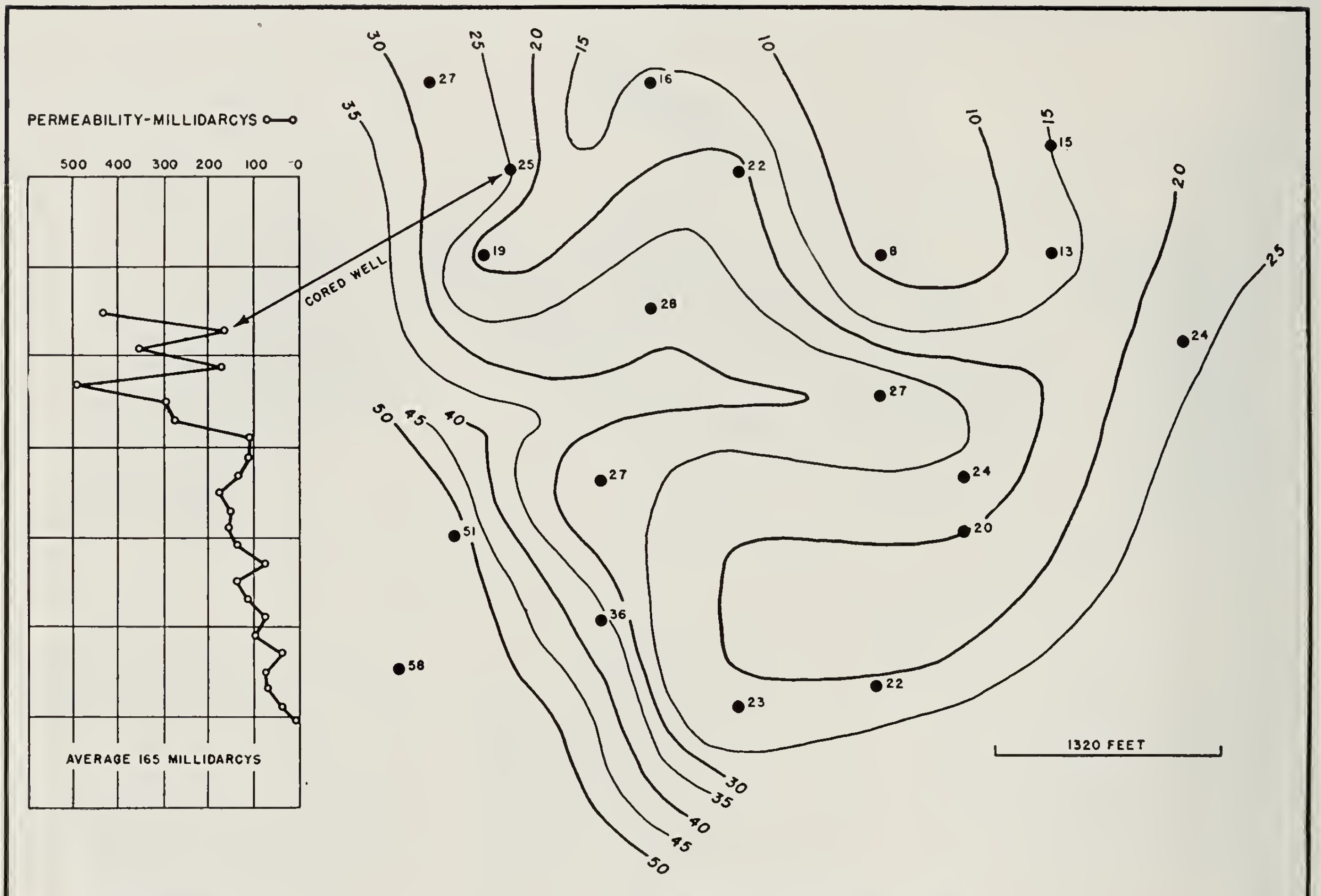
Test for extension. The direction of the extension of permeable and therefore probably productive sand beyond a drilled area may be explored by closing in the casingheads of all output wells, creating a high artificial pressure on the sand through a central input well, and observing the immediate pressure and the rate of pressure decline at each output well (Fig. 14). The pressure will decline most in the direction of the outside areas of permeable sand because the injected gas will escape from the drilled areas into them in an effort to establish equilibrium.

Test by tracer gas. The continuity of a sand may be determined by injecting a tracer gas into an input well and testing for its presence or absence in the gas from output wells.

Test by pressure-volume relationships. When many records have been taken, pressures and corresponding volume input rates for a single well may be plotted on a graph (Figs. 16, 17). If log-log graph paper is used, the points generally fall into a straight-line pattern which may be easily extrapolated. If a core has been taken on an input well it is possible to compare the two methods of







CORE PERMEABILITY PRESSURE-VOLUME RELATIONS 16

measurement and to relate the results to other territory on which there are only pressure-volume records. This is illustrated in the drawings, where a core analysis has been made for an input well. The analysis shows an average permeability of 165 millidarcys. Afterward this well took 20,000 cubic feet of gas per day at a pressure of 25 pounds per square inch. All the input wells in the immediate vicinity were graphed for pressure-volume relationship. The pressures found were set down on a map and contours showing equal pressures were drawn as shown.

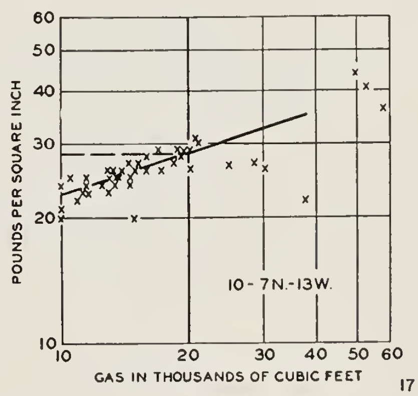
Test by speed of gas travel. Relative permeabilities of the sand between input and surrounding output wells may be measured by speed of travel of injected gas. When injection is begun on a new operation, the time required for injected gas to reach each output well can be noted and a map of the area contoured with lines representing equal time intervals. The resulting picture gives measurements of relative permeabilities. This may be done at any later time by using tracer gas, noting the time of arrival of the tracer at the output wells, and drawing a contour map as above. Air is a good tracer gas, as are carbon dioxide, helium, and many others.

The methods described may be used by the water-flood operator to gain a general knowledge of sand permeabilities in gas injection territory. What the methods lack in exactness they make up for in the vastness of the areas they are able to cover.

5. Tests for Water Encroachment

Four methods for determining the direction, speed, and results of encroaching edgewater on Illinois oil pools are shown in Figs. 18-21.

The first consists of a map contoured on similar dates of abandonment. Then the pumping time of the remaining wells is found and contoured to show equal lengths of pumping time. The third and most illuminating set of facts, involves the fluid levels in producing wells after they have come to equilibrium. When these are contoured on intervals of equal height, a map results which indicates, from higher to lower, the direction in which the water is moving. The fourth method is applied after the cumulative oil production by farms is obtained. The farms are hatchured with lines indicating, by closeness, the variation of production per acre. Often this shows that oil has been moved ahead of the flood and has been produced on farms which it did not originally underlie.



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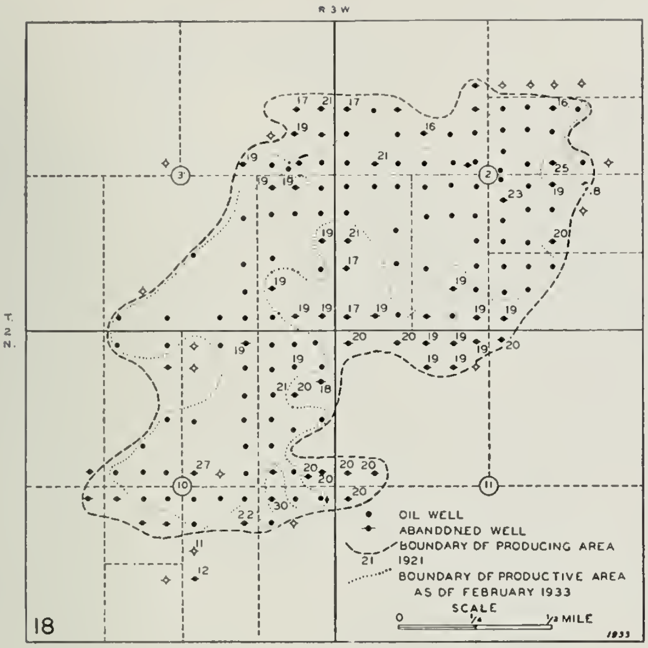
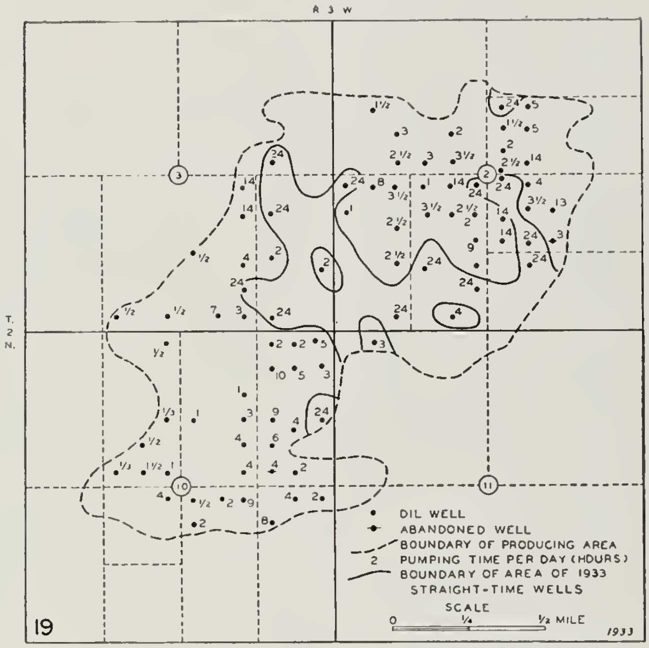
Figures 13, 14, 15, 16, and 17 show methods of exploring the characteristics of oil sands by the travel of injected gas. Figure 13 determines relative permeability by volume. Figure 14 illustrates exploration beyond the drilled area. Figure 15 demonstrates the test for continuity of stratum. Figures 16 and 17 show means for determining relative permeability by injection of uniform volumes and observing consequent pressures. Illustrations from Illinois Geological Survey Circular 145.





6. Equipment for New Conditions

Caliper, Core-drill and Rotor Valve. The shot-hole caliper, (Figs. 22, 23) the shot-hole core-drill (Fig. 24), and the rotor valve (Fig. 25) are three oil field tools designed to solve problems presented by Illinois water flooding. The first two tools supplement each other in the process of finding permeabilities of the sand in old wells. The third is for measuring and regulating the flow of water from an upper water sand into a lower oil sand.

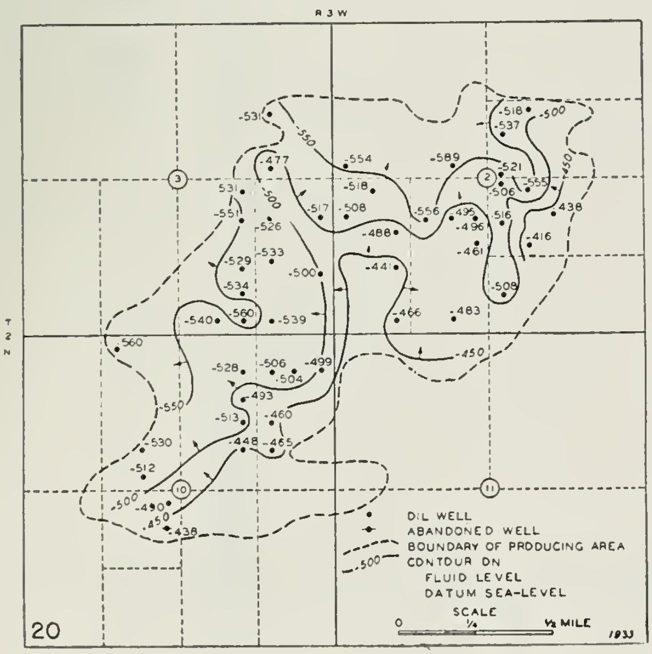
The rotor valve is necessitated by the relatively new practice of flooding lower oil sands with water supplied directly from the upper water sands in individual wells. In many cases, as at Allendale and in the basin McClosky, the amount of water admitted by gun perforating the casing, without measuring or regulating, is too great and its travel from water well to oil well is too fast. The rotor-operated valve is intended to overcome this difficulty by keeping the input volume of water down to a desired steady rate.

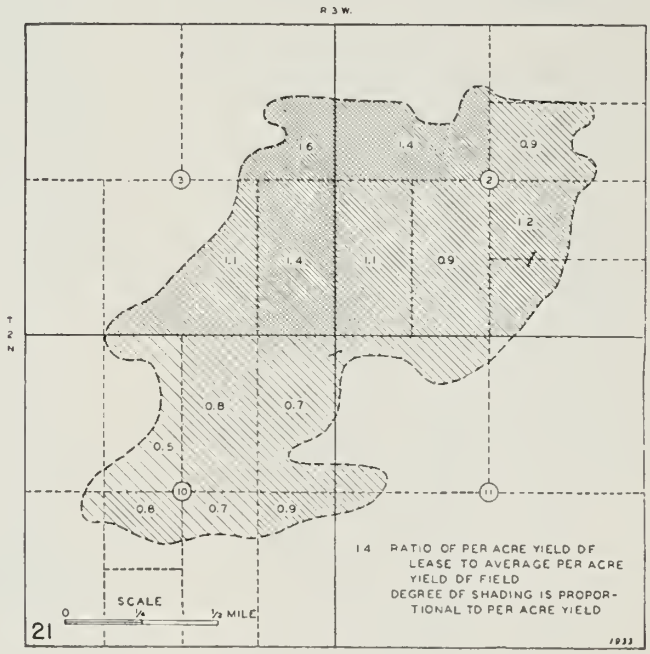
The Acid Drill. It has been only during the last few years that attention has been called to the possibilities of chemicals as a means of drilling holes in deeply buried oil-producing limestone formations (Figs. 26, 27). Research carried on in laboratory and field has resulted in the develop-

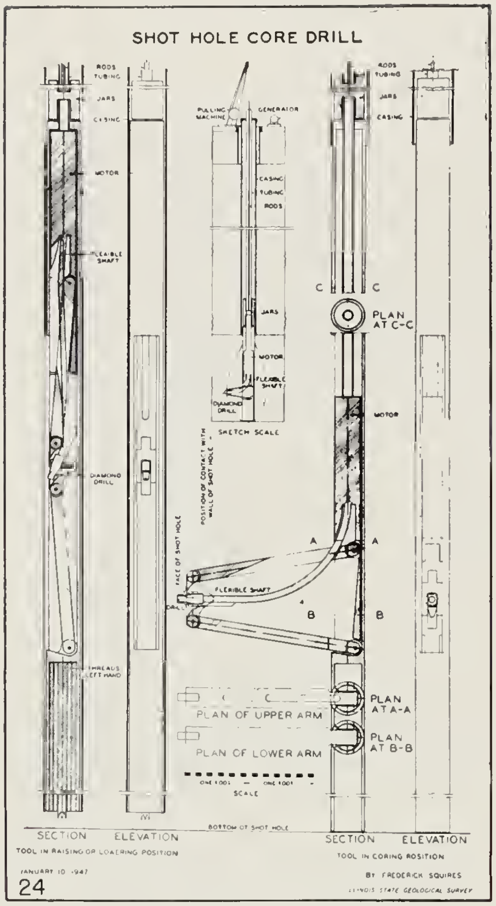
Figures 22-30. Figures 22 and 23 demonstrate the use of a mechanical caliper for shot holes. Figure 24 shows a side-wall coring tool for use in shot holes of old wells. Figure 25 illustrates an automatic meter and regulator for use in flooding a lower oil sand with water from an upper sand. Figures 26 and 27 show two methods of acid drilling. Figures 28 and 29 illustrate the Safety cylinder. Figure 30 is a working drawing of a Ford engine converted into a compressor.

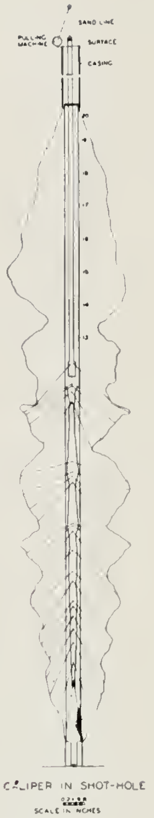
Figures 22, 23, 24, and 25 from Circular 130, Figures 26 and 27 from Circular 107, Figures 28 and 29 from Circular 93, Figure 30 from Circular 97.

Figures 18, 19, 20, and 21 show four techniques for measuring natural water encroachment. Figure 18 shows progress measured by time of abandonment of wells. Figure 19 shows water content measured by well pumping time. Figure 20 indicates direction of water advance by decrease in fluid columns in wells after fluid has reached practical equilibrium. Figure 21 shows the progress of encroachment by the increases in per acre yield of oil. From Illinois State Geological Survey's Report of Investigations No. 89, 1943.









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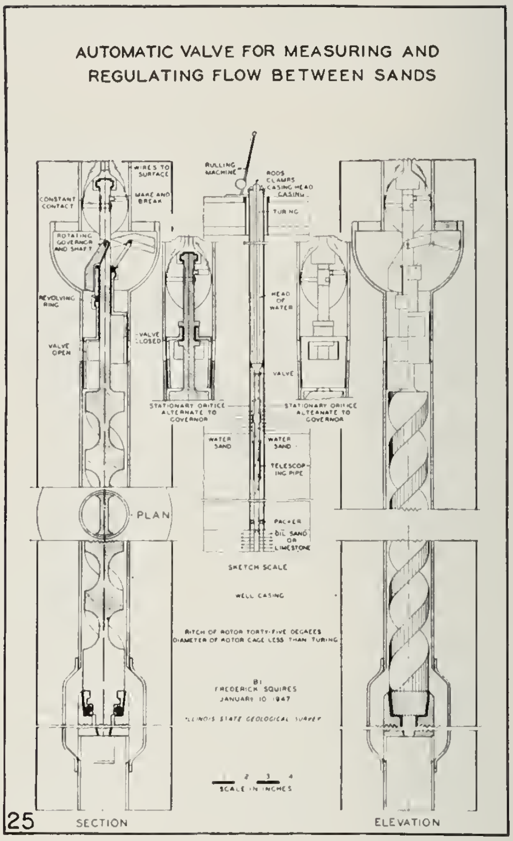
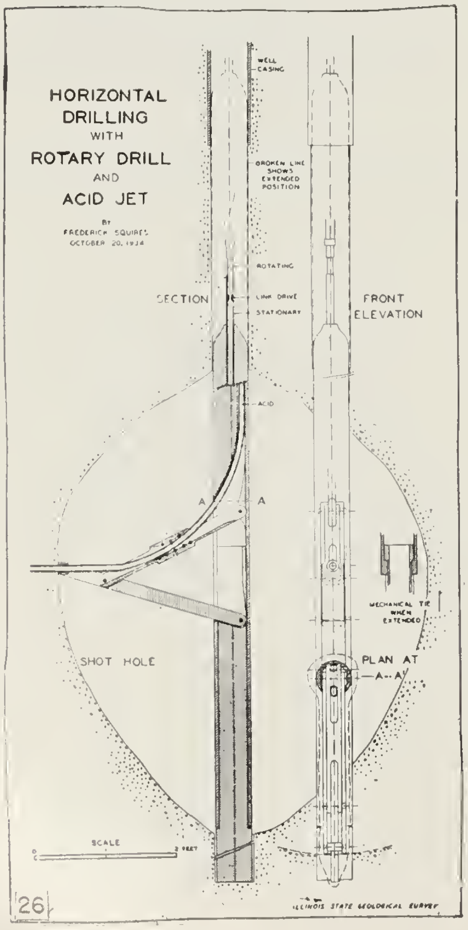
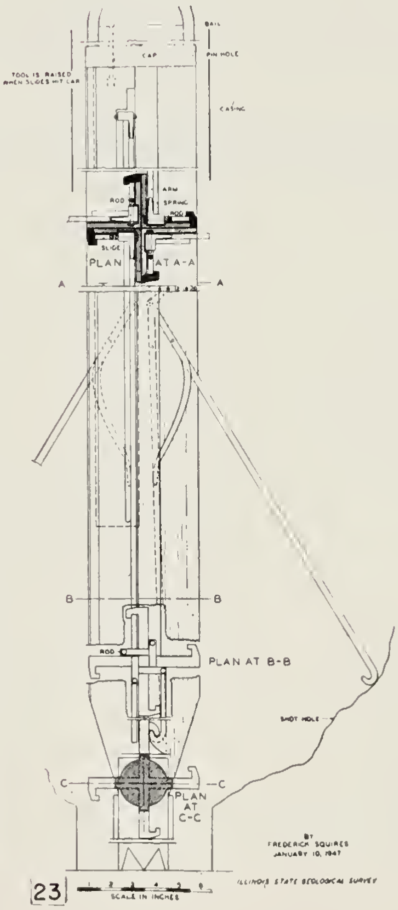
SHOT-HOLE CALIPER







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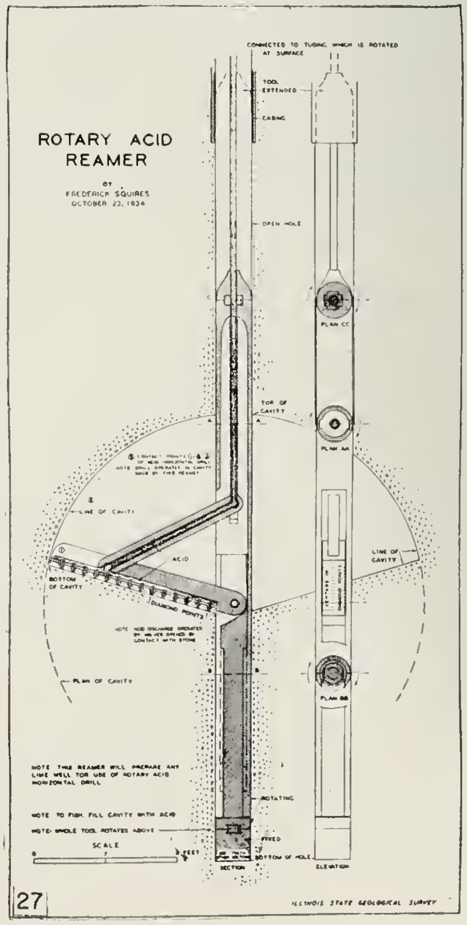

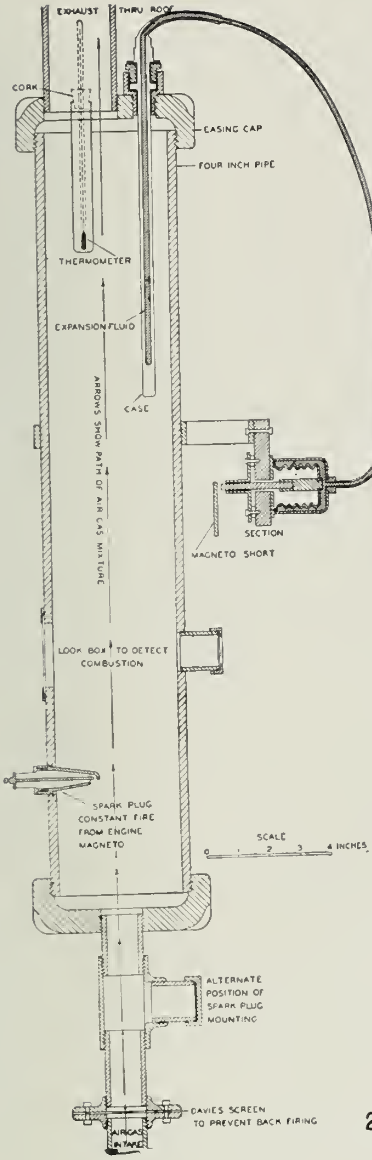

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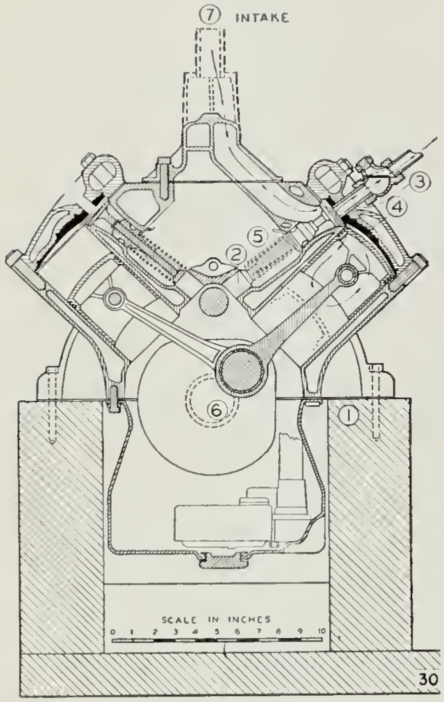

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ment of a horizontal drilling device which utilizes a flexible pipe as a guide for armored hose, ending in a drill head with suitable jets. Acid is pumped through the rotating jet against the formation. The combination of drilling and solvent jetting action digs a hole into the formation.

This tool has been used in Illinois and in other areas. For example, a hole was drilled horizontally a distance of 40 feet into the Kansas City formation. Other acidizing procedures suggested by Survey research are heat and agitation and the rotary acid reamer.

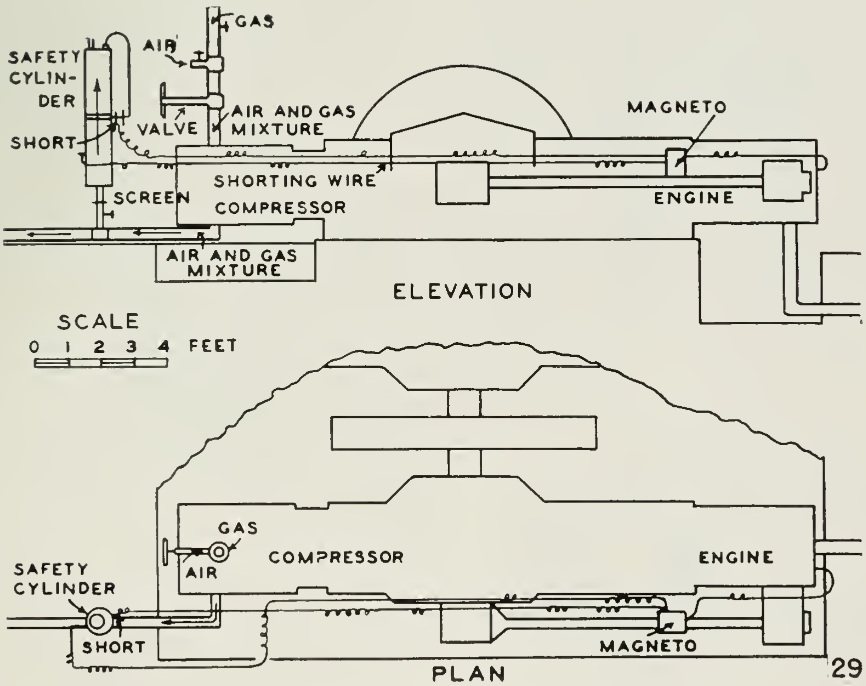
The Safety Cylinder. In oil fields, gas is depleted sooner than oil, and because repressuring operations have been confined mostly to old producing properties, the principal problem has been to find an adequate pressure medium for the compressors and adequate fuel for the engines. This is usually solved by using all the available gas and making up any deficit by adding air. Such a practice often results in explosions in the compressors and lines when the mixture of air and natural gas has entered the explosive range and is accidentally touched off. The safety cylinder (Figs. 28, 29) is designed to avoid such danger.

It is set up at some convenient place in the compressor house with the vent pipe extending to outside air, preferably through the roof. A wire is run from the compressor engine magneto to the spark plug on the cylinder. A second wire runs from the shorting mechanism opposite the plunger of the sylphon valve back into the same magneto.

A small pipe runs from the compressor discharge line to the intake of the safety cylinder. The protection operation is as follows: All the while the compressor is running, a small regulated stream of the air-gas mixture flows through the safety cylinder past the hot spark plug, up and out of the exhaust outlet. Whenever this mixture reaches explosive proportions, it ignites in the safety cylinder, raises the temperature there, thus expanding the fluid in the sylphon valve and forcing the sylphon valve plunger into the contact with the magneto short. This instantly cuts off the engine ignition and shuts down the plant. Changes to safe proportions of air and gas are then made by hand before the plant is started up again.

The regulation of the proportion of air and gas may be made automatic by maintaining a uniform supply of gas and causing the plunger of the sylphon valve to operate a ratcheted valve handle on the air line automatically and continuously as long as the mixture ignites, thus reducing the amount of air admitted into the mixture until the mixture is below the explosive range.

Automobile Engines Changed into Compressors. Quantity-produced low-priced cars provide engines adapted to conversion into compressors. The Geological Survey converted a Ford V-8 engine into a compressor at a time when compressors were hard to get (Fig. 30). This compressor was run at 900 r.p.m. and delivered 105,000 cu. ft. per day, against atmos-



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phere. It required 15 hp. at 120 lb. per sq. in. pressure.

7. Cemented Fibre Casing

A new method of casing oil wells was successfully used in a well in the Casey pool, in the W. 1/2 NW¼ sec., T.9 N., R 12 W., Johnson Township, Clark County, Illinois. This method utilized fibre pipe instead of steel casing (Figs. 31-34).

The test was arranged and supervised by the Illinois Geological Survey with the joint cooperation of Dinsmore Oil Company, owners of the well; Halliburton Oil Well Cementing Company, and Fibre Conduit Company. For deeper wells, encountering higher pressures, asbestos cement pipe and joints were designed.

8. Thermal Drive

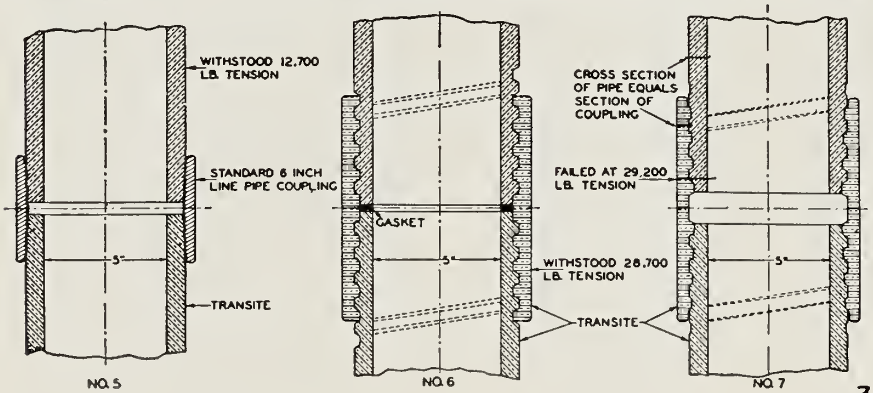
Recovery of additional oil by fluid injection has been developed to a point where it is known and practiced in nearly every extensive oil field. It has been subjected to the best thought of practical oil men and scientists. But even when all that is known about the best methods for using fluid injections has been put into efficient practice, nearly half the oil originally contained in the reservoir cannot be produced and is abandoned under ground. It is possible that heat treatment may recover some of this oil, otherwise lost.

The separating out and expansion of solution gas requires heat which is subtracted from the reservoir contents; this automatically increases the viscosity of the oil. Add to this the chill, caused, on repressured properties, by the expansion of vast volumes of input gas, and the result is a decided check on the movement of oil. Any method of cancelling out this cooling effect will be beneficial, and it is here proposed to do it by superheating input gas that has already been raised in temperature by compression. Such a method will be most successful in highly permeable sands, which will not subtract heat from the injected gas as fast as would tighter sands. If the vented gas from an oil field could be turned into heat in the reservoir, we would produce far more of the oil.

Preheated gas will evaporate the lighter fractions of the oil and carry them along in the gas stream. As the enriched gas exits from the output well, its heavy parts may be absorbed by counter current contact with stripped oil pumped into the output well head. If this "absorption tower" output well is provided with a filling presenting great surface, as is done in above-ground absorbers, it will be more effective. So also will be the chilling of the stripped oil before injection into the top of the well. This stripped oil will join the produced oil at the well bottom and be pumped with it to the surface.

The next attack on oil production from old fields may be the study of the use of heat.

Figures 31, 32, 33, and 34 show pipe couplings and shoe for non-ferrous cemented-in oil well casing. Figures 31, 32, and 33 are from Circular 120, Figure 34 is from Illinois Petroleum 40.



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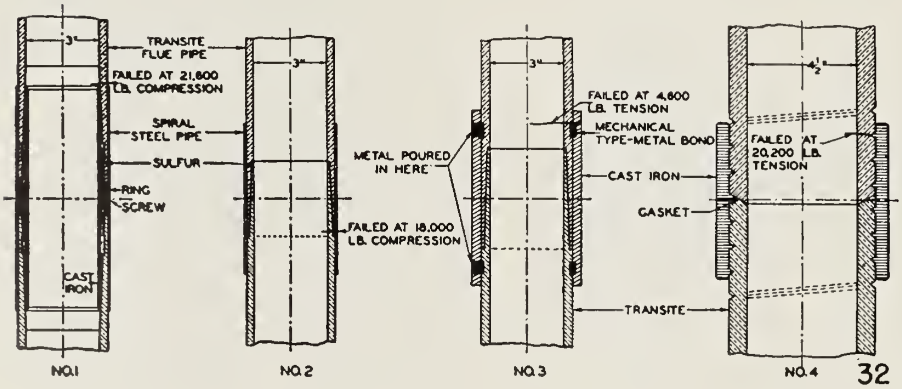

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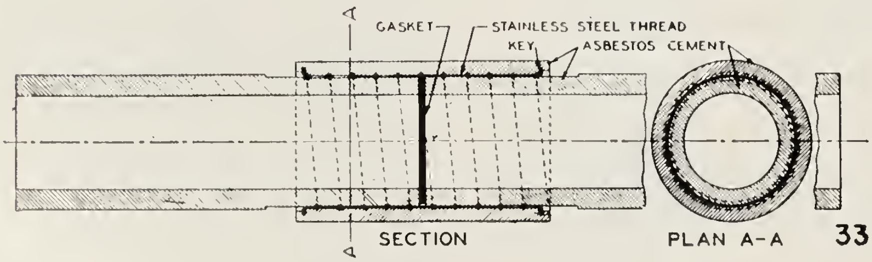

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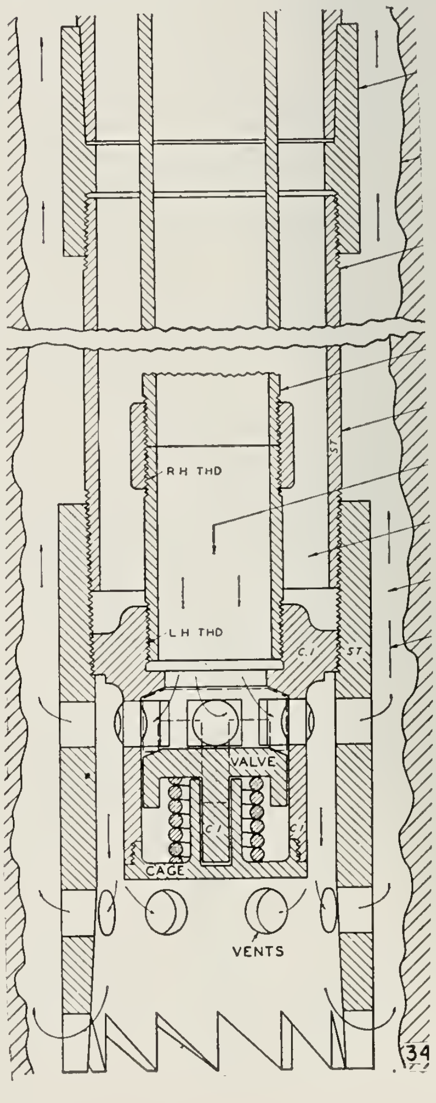

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SUMMARY

There have been presented brief descriptions of the results of research directed toward the solution of problems arising from the unusual characteristics of Illinois oil sands. Flooding with old wells, wide well spacing, use of brine for the flooding fluid, subsurface flooding, selective plugging with water, exploring sands with gas, tracing water encroachments, conversion of engines to compressors, drilling with acid, and casing with nonferrous pipe have all been put to use ~~returns from widely spaced and sub-~~ Returns from wide spaced and subsurface flooding have been spectacular. Wider well spacing, the use of old wells without new drilling, and the use of brine as the flooding medium have made flooding costs compare favorably with gas repressuring. All this research has paid out.

Conjoint use of gas and water, which has been highly successful in the Shuler Jones pool in Arkansas and the West Tepetate pool in Louisiana, gives great promise for Illinois, especially for the Johnsonville pool. The use of heat may well be the next step in production progress.

ACKNOWLEDGEMENT

This paper is the work of many hands. From the beginning of this research to the present day is a long span, and during all this time Alfred H. Bell, head of the Oil and Gas Division of the Illinois State Geological Survey, has kept the efforts headed in the right direction. Many others have helped in many ways and the writer takes this opportunity to thank them all.

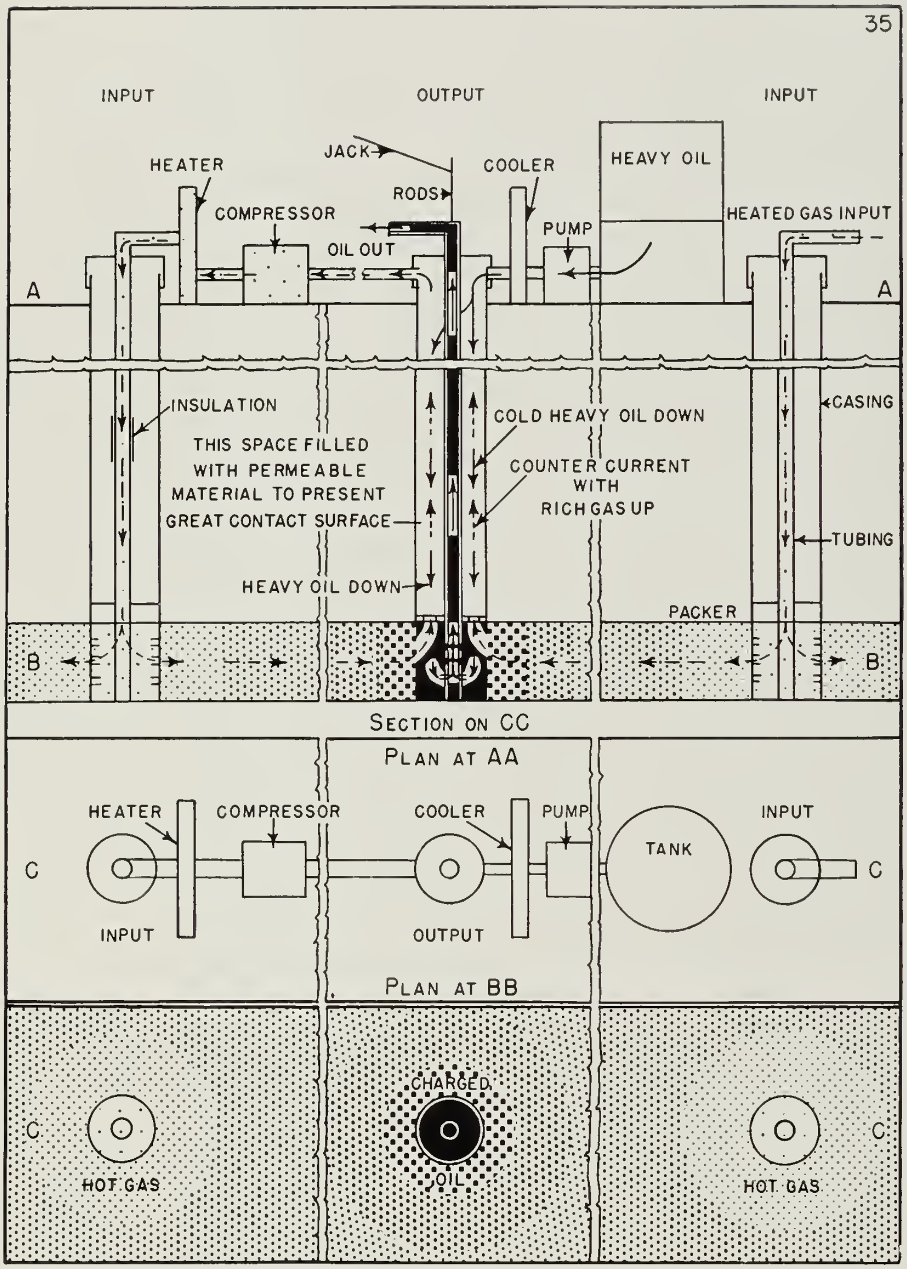

Figure 35 illustrates the first steps toward the Thermal Drive. Preheated gas and a well used as an absorption tower are the principal features.

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